

# Process and device for in-situ decontamination of a EUV lithography device.

## Description

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The invention concerns a process as well as a device for in-situ decontamination of an EUV lithography device.

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EUV lithography devices are used in the manufacturing of semiconductor components, e.g. integrated circuits. Lithography devices, which are operated in the wavelength range of extreme ultraviolet (e.g. at a wavelength of 13.4 nm), have primarily multi-layered systems of molybdenum and silicon, for example, as optical elements. EUV lithography devices display a vacuum or an inert gas atmosphere in their interior, however hydrocarbons and/or other carbon compounds cannot be completely prevented from appearing inside the device. These carbon compounds are split by the extreme ultraviolet radiation, leading to a film of contaminated carbons precipitating on the optical element. This contamination by carbon compounds leads to significant losses in reflectivity on the optical surface, which can have a considerable impact on the cost-efficiency of the EUV lithography process.

The problem of contamination is of great significance not only in the case of lithography devices.

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In WO 87/02603 a process is described in which satellites, space shuttles, rockets and probes are cleaned during the flight, in which a stream of oxygen, i.e. a ray of oxygen ions is aimed at the external surface to be cleaned. The UV radiation from the sun is used to create additional ozone. Both the oxygen and the ozone react with the carbon contamination by volatile compounds. A sensor can be provided to steer the cleaning process, i.e. to determine when the cleaning process should be started and ended.

According to US 5,024,968, substrates, especially silicon substrates are cleaned of contaminating carbon compounds using UV lasers with a wavelength between 200 and 300 nm. The laser focusing is controlled by the results of residual gas analyses. The substrate is thoroughly washed with inert gas to protect against renewed contamination.

In EP 0 660 188 B1, a lens system is washed with inert gases and externally produced ozone as a protective measure against contamination.

In the publication from E. D. Johnson et al., NIM A266 (1988) 381, the process of how X-ray monochromators are purified in-situ via glow discharges is explained. For this purpose, a glow discharge reactor with oxygen and water lines is connected directly to the monochromator box. The purification process lasts approximately 24 hours. The end of the cleaning process is determined by means of residual gas analyses or spectrometric measurements. A more elaborate method for determining the degree of contamination consists of pumping out the monochromator box from time to time and measuring the reflectivity of the monochromator box.

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According to JP H110329931 A, the electrical resistance on the mask is measured during electron radiation lithography in order to determine if the mask must be decontaminated or not. The lithography has several masks available, so that as soon as one mask needs to be cleaned, it can be replaced by a clean mask in reserve. The mask to be cleaned is removed from the radiation process and purified in a side chamber using radiation with ultraviolet light and rinsing it with oxygen.

In EP 0 421 745 B1 a device for decontaminating optical elements is described. For this purpose, gas supply equipment as well as control equipment to select the desired wavelength range for the radiation is set up beside a reaction chamber which holds the optical element to be cleaned. In effect, oxygen and UV radiation is used to photochemically corrode the contamination based primarily of carbon compounds.

In EP 0 874 283 A2, a lithography device is described. The degree of contamination within the device is determined via transmission measurements, and in the event that a threshold value is exceeded, an in-situ purification process is initiated. The UV light used for exposure (ArF Laser, 193 nm) is used for purification. To this end, the exposure process is interrupted and an optical element, e.g. a prism, is inserted into the radiation beam path, which changes the radiation process in such a way that the greatest number of places within the lithography devices are illuminated. The atmosphere inside the lithography device is made up of nitrogen. To support the purification effect, oxygen, ozone or oxygen radicals can be mixed in with the nitrogen. The degree of contamination is also continuously monitored during purification via transmission measurements, and in the event that the threshold value is not met, the purification process is ended.

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Against this background, the task of the invention submitted is to provide a process, i.e. a device for decontaminating an EUV Lithography device, by which standstill periods are avoided and equipment changes to the EUV lithography device to be cleaned are kept to a minimum.

This task is solved by a process according to Claim 1 as well as by a device according to claim 9.

Surprisingly, when it was determined that when a targeted supply of oxygen is fed to the lithography device, the radiation in the beam path used for exposure is sufficient to clean the inside of the device from contamination, as long as the degree of contamination is monitored continuously and compared with the pre-set threshold values. Depending on the actual degree of contamination, the oxygen supply is adjusted for the lithography device. The oxygen supplied is activated in the exposure beam path, spreads out via diffusion and light convection throughout the entire interior of the lithography device and reacts with the layers of contamination.

By continuously monitoring the level of contamination, it can be ensured that the purification process is initiated even if the level of contamination is so low that the normal exposure process is not yet impaired. In addition, since even minor changes in the level of contamination are detected by continually monitoring of the level of contamination, the oxygen supply can be adjusted so that very minor oxygen partial pressures are sufficient to decontaminate the EUV lithography device. This has the advantage that the oxygen is present in the lithography devices in such small amounts that the exposure process is not impacted negatively.

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With the exposure radiation in the extreme ultraviolet wavelength range, especially at 13.4 nm, the oxygen molecules  $O_2$  supplied are split into highly reactive oxygen atoms, which in turn oxidatively break down the contaminated film of carbon compounds on the optical element. Too strong of an oxygen supply may result in an oxidative attack on the silicon layer of the multi-layered, molybdenum -silicon system during cleaning. In this case, a layer of quartz ( $SiO_2$ ) forms on the surface, which would also lead to a loss of reflection similar to contamination. Using the process according to the invention, however, such impairments to the surface can be prevented. Hence, with the help of the process according to the invention, just the right amount of oxygen is supplied so that the entire film of contaminating carbon and only the contamination containing carbon is removed.

The device according to the invention to decontaminate the optical elements of an EUV lithography device has at least one measuring device to measure the degree of contamination to the optical element(s) as well as a connected control device, which is connected on its side to the  $O_2$  supply and is designed to compare the degree of contamination with at least one preset threshold value and to control the supply of oxygen based on the respective comparison results. Preferably, the measuring device will supply measured values for the degree of contamination on a continuous basis.

A computer is preferably used as the control device. The computer can, for example, be connected with a dosing valve that is opened and closed by computer so that doses of oxygen are added to the vacuum of the EUV lithography device at a certain pressure and at a specific flow rate. The flow measurement can, for example, be made using a flow meter, the partial pressure measured with vacuum measurement tubes

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(Bayard-Alpert type, capacity measuring, etc.) or a residual gas mass spectrometer. Any potential excess oxygen or reaction products are evacuated from the pump(s) in the lithography device in any case.

In order to accelerate the decontamination process, it has proven to be beneficial to set up at least one light source within the decontamination device to provide radiation in the wave length range between 150 nm and 300 nm. Particularly at a wavelength of 185 nm or 254 nm, highly reactive ozone is formed from the oxygen supplied. According to the invention, at least one light source is connected to the control device, and the UV radiation dosing is regulated at the same time with the O<sub>2</sub> supply.

Fortunately, the level of contamination can be measured with one or several oscillators that react to a change in their surface mass through a change in the resonance frequency. In a preferred embodiment, at least one measuring device is shown and at least one quartz crystal microwave is arranged inside the lithography device. With quartz crystal microwaves, the smallest amount of contamination can be detected on a coated piezoelectric quartz.

The detection sensitivity of the quartz crystal microwaves reaches the mono and sub-mono layers. The key is correctly choosing the fundamental frequency for the piezoelectric quartz. The higher the frequency, the more sensitively the piezoelectric quartz reacts to changes in its surface mass. The contamination film on the piezoelectric quartz expresses itself in a disturbance to the base frequency of the piezoelectric quartz.

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The change in frequency to the piezoelectric quartz can be traced back to the changes in mass due to the film of precipitating contamination. The change in frequency has a linear relationship to the change in mass.

In another preferred embodiment, the decontamination device has at least one additional light source and at least one detector, which are arranged inside the lithography device. The degree of contamination is then preferably determined via reflectivity measurements. The reflectivity of optical elements, in particular, is very strongly dependent on possible contamination. Apart from the high level of sensitivity toward possible contamination, this measuring method has the advantage of using reflectivity measuring to determine the most important target size for the lithography device.

In a similarly preferred embodiment, a polarizer is set up in the beam path from at least one light source, near the light source and an analyzer is set up near the detector. In this way, the formation of the layer of carbon contamination and its destruction using oxidative purification can be traced ellipsometrically. In this case, a helium-neon laser is selected as the light source. Its light is beamed from outside into the EUV lithography device through a corresponding port or glass window. Monitoring the density of the carbon contamination coating is possible by measuring the p- and s- polarized laser light reflected.

Another preferred embodiment consists of providing the means to measure the flow of photons within the framework of the measuring device, and connecting this to optical elements in the EUV lithography device. In the event of the formation of a contaminated layer of carbons on the molybdenum-silicon, multi-layered

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systems in a EUV lithography device, a change in the photon stream occurs, which can be measured with radiation in the application wavelength of extreme ultraviolet, e.g. 13.4 nm.

According to another embodiment, a residual gas measuring device is included, which is connected to the control unit. Using the residual gas-measuring device, the level of contamination is determined via residual gas measurements. Since the oxygen supply and the resulting oxidative purification process removes the layer of carbon contamination, changes in the particle pressure of CO and CO<sub>2</sub> can be measured. As soon as the carbon is oxidatively cleaned off from the surface of the optical element, the corresponding particle pressures of CO and CO<sub>2</sub> fall off. The change in these particle pressures can serve as a way to measure the oxidative removal of the layer of contaminated carbons.

For decontamination of EUV lithography devices for use in manufacturing processes, in which the demands for cost-efficiency are higher than those for quality, it has proven to be sufficient within the previously described measuring method to provide a precise threshold value for the level of contamination, e.g. the density of the contamination layer. When the threshold value is exceeded, oxygen is added in a partial pressure range of  $1 \times 10^{-10}$  mb to  $1 \times 10^{-3}$  mbar. If the threshold value is not achieved, the oxygen supply is stopped. In this case, the control unit for the decontamination device can be simply set up as the discriminator switch.

In addition, to increase the quality and efficiency of the process and the device, it is of course possible to interconnect several measuring methods for determining the degree of contamination.

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The invention should ~~be~~ explained in more detail using a sample embodiment.

Figure 1 shows a schematic diagram of the control circuit for controlling the degree of contamination, i.e. removing the contamination.

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The figure shows a schematic illustration of a sample embodiment, in which the dotted line indicates vacuum recipient 1 within the EUV lithography device, or in larger installations, vacuum recipient 1 in which the EUV lithography device as a whole is set up. Optical element 2 and the quartz crystal microwave 3 are set up within vacuum recipient 1. Optical element 2 involves reflectors with molybdenum-silicon, multi-layered systems for a wavelength of 13.4 nm. At this wavelength, the silicon-wafer is exposed by means of the lithography device.

In order to obtain the same conditions with quartz crystal microwave 3 as for optical element 2 within the EUV lithography device, the piezoelectric quartz in quartz crystal microwave 3 is equipped with a corresponding molybdenum-silicon, multi-layered coating. Moreover, the quartz crystal microwave 3 is arranged within vacuum recipient 1 in such a way that the piezoelectric quartz is exposed to EUV radiation of the same intensity, i.e. power density, as for optical element 2.

The formation of a contaminated film on the piezoelectric quartz leads to a disturbance in the base frequency of the piezoelectric quartz. While operating the EUV lithography device, the quartz microwave 3 continually misses the precipitating contamination from the radiation due to the corresponding frequency change, which is proportional to the mass of precipitating contamination.

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Computer 4 processes the change in frequency and compares it with the original base frequency of the contamination-free piezoelectric quartz and the molybdenum-silicon multi-layered coating. As soon as a frequency deviation is present, as a result of the formation of a layer of carbon contamination, the computer opens the dosing valve for the oxygen supply 5a. The amount of oxygen fed through the dosing valve is controlled by measuring the partial pressure and flow. The mercury low-pressure lamp 5b can also be linked up as needed to produce UV radiation. The oxygen fed into vacuum recipient 1 breaks down the contamination film oxidatively. In the event that in addition to the mercury low-pressure lamp 5b, UV light is radiated into vacuum recipient 1, additional ozone is created which breaks down the contamination film anyway.

During the entire purification process, the frequency of the quartz crystal microwave 3 is measured, and computer 4 decides whether the oxygen supply should be modified and if UV radiation should be added. Toward that end, computer 4 can store parameters that indicate oxygen partial pressure and/or the intensity of the UV radiation in relation to the measured frequencies. In controlling the degree of contamination using a quartz crystal microwave, the piezoelectric quartz must be precisely temperature-controlled (better than  $\pm 1$  K) in order to obtain reliable frequency measurements.

In a simple variation, the base frequency can also serve as the threshold value. In the event that the measured frequency is not the same as the basic frequency, oxygen is added; as soon as the base frequency is achieved again, the supply of oxygen is cut off.

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Analogous to the embodiment samples shown in the figure, instead of the quartz crystal microwave 3, a medium can be provided to measure the photon stream or a light source and a detector to measure the reflectivity, i.e. in connection with a polarizer and analyzer to determine the density of the contamination layer ellipsometrically. In addition, while oxygen is being supplied, residual gas analyses can help determine how much contamination has already been broken down, and this data from the computer can be used to check the amount of contamination and adjust the supply of oxygen.

The above-mentioned example is only described for a quartz crystal microwave 3. Of course, quartz crystal microwaves and other measuring tools can be set up at various places within vacuum recipient 1 in order to precisely determine the degree of contamination. Accordingly, a large number of the oxygen lines and dosing valves 5a can be provided, so that various local oxygen partial pressures can be set up according to the differing degrees of contamination.

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